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Towards FAA Certification of UAVs

Stacy Nelson

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FOR

NASA Ames Research Center

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TABLE OF CONTENTS

RECORD OF REVISIONS

REVISION	DATE	SECTIONS INVOLVED	COMMENTS
Initial Delivery	6/30/03	All Sections	Version 1.0

1 TERMINOLOGY

The following terminology is used throughout this document:

Certification - legal recognition by the certification authority that a software product complies with the requirements[1]

Mission critical: *Mission critical* means the loss of capability leading to possible reduction in mission effectiveness[2] Examples of mission critical software can be found in unmanned space missions like Deep Space One and others. Also called Class B software at NASA.

Safety is a property of a system/software meaning that the system/software will not endanger human life or the environment.

Safety-critical means failure or design error could cause a risk to human life.[2] Examples of safety-critical software can be found in nuclear reactors, automobiles, chemical plants, aircraft, spacecraft, et al. Also called Class A software at NASA.

2 INTRODUCTION

As of June 30, 2003, all Unmanned Aerial Vehicles (UAV), no matter how small, must adhere to the same FAA regulations as human-piloted aircraft. These regulations include certification for flying in controlled airspace and certification of flight software based on RTCA DO-178B. This paper provides an overview of the steps necessary to obtain certification, as well as a discussion about the challenges UAV's face when trying to meet these requirements. It is divided into two parts:

- Certifications for Flying in Controlled Airspace
- Certification of Flight Software per RTCA DO-178B

3 CERTIFICATIONS FOR FLYING IN CONTROLLED AIRSPACE

It seems reasonable to assume that the FAA could certify a UAV for flight if the autonomous vehicle could meet or exceed the certification requirements for human pilots and the aircraft they fly. What are these requirements and what challenges do UAV's face when attempting to comply? The Federal Aviation Regulations/Aeronautical Information Manual (FAR/AIM) explains requirements for pilot and aircraft certification as well as rules pertaining to airspace.

The following section describes pilot and aircraft certification criteria as a foundation for understanding airspace designations and rules for aircraft operations. Then, subsequent sections explain airspace and aircraft operations and discuss the challenges faced by UAV's in meeting these requirements.

3.1 Pilot Training

According to the FAR 61.3: *A person may not act as pilot in command or in any other capacity as a required pilot, flight crewmember of a civil aircraft of U.S. registry unless that person has a valid pilot certificate readily accessible in the aircraft during flight*[3]

There are currently no rules regarding a "non-human" pilot like an autonomous flight controller. However, careful investigation of human pilot requirements may lead to ideas about how to certify an autonomous flight controller.

The FAR describes two methods for becoming a pilot, commonly referred to as FAR 61 and FAR 141. FAR 61 contains the criteria for obtaining pilot, flight instructor and ground instructor certificates and ratings obtained under the tutelage of an independent certified flight instructor (CFI). FAR 141 contains the requirements for a pilot school certificate and criteria for obtaining pilot, flight instructor and ground instructor certificates and ratings from a flight school.

In general the required flight time tends to be lower for FAR 141; however, it may be unlikely that an autonomous rotorcraft would qualify to attend a FAR 141 flight school. The following section provides an overview of FAR 61 and FAR 141 requirements for the five types of pilot certificates plus the instrument rating:

- Student Pilot
- Recreational Pilot
- Private Pilot
- Instrument Rating
- Commercial Pilot
- Airline Transport Pilot

3.1.1 Student Pilot

Under FAR 61, a student pilot must have a Third Class Medical Certificate before soloing. A student pilot may not act as pilot in command of an aircraft carrying a passenger or for hire to carry property (parcels, etc), in furtherance of business or with visibility less than 3 statute miles during the day or 5 statute miles at night.

3.1.2 Recreational Pilot

Under FAR 61, a recreational pilot must be at least 17 years old with a Third Class Medical Certificate and successful completion of the training described in Table 1. A recreational pilot may carry no more than one passenger and not pay less than pro rata share of operating expenses of a flight (fuel, oil, airport expenses or aircraft rental fees) with a passenger. A recreational pilot may only act as pilot in command within 50 nautical miles from the departure airport.

Table 1: Recreational Pilot Training Requirements Overview

Training	**FAR 61**	**FAR 141**
Ground school	Home study or flight school	
Total Flight time	15 hours dual instruction	Requires a student pilot certificate and 30 hours of flight training of which 15 hours must be dual instruction
Takeoffs and Landings	3 at an airport	3 at an airport
Cross Country	2 hours flight training en route to an airport located more than 25 nautical miles from applicant’s home airport	2 hours flight training en route to an airport located more than 25 nautical miles from applicant’s home airport
Flight training within 60 days preceding test date	3 hours	3 hours
Solo time	3 hours	3 hours

3.1.3 Private Pilot

Under FAR 61, a private pilot must be at least 17 years old with a Third Class Medical Certificate and successful completion of the training described in Table 2.

Private pilot certificate has no expiration date but periodic renewal of the medical certificate is required. A private pilot may not pay less than pro rata share of the operating expenses (fuel, oil, airport expenses or aircraft rental fees) of a flight with passengers and except for special exceptions, like an aircraft salesperson, may not profit from flying.

Table 2: Private Pilot Training Requirements Overview

Training	FAR 61	FAR 141
Ground school	Home study or flight school	35 hours
Total Flight time	40 hours with at least 20 hours dual instruction	35 hours flight training with at least 20 dual instruction
Night Flight	3 hours	3 hours
Takeoffs and Landings	10 at an airport	10 at an airport
Cross Country	3 hours of cross-country flight training including one cross-country flight of over 100 nautical miles total distance	1 cross-country flight of more than 100 nautical miles total distance in airplane and 50 nautical miles distance in helicopter
Instrument Training	3 hours of instrument training including straight and level flight, constant airspeed climbs and descents, turns to a heading, recovery from unusual flight attitudes, radio communication and use of navigation systems and radar services appropriate to instrument flight	3 hours of instrument training including straight and level flight, constant airspeed climbs and descents, turns to a heading, recovery from unusual flight attitudes, radio communication and use of navigation systems and radar services appropriate to instrument flight
Flight training within 60 days preceding test date	3 hours	3 hours
Solo time	10 hours solo flight time including 5 hours of solo cross-country and one solo cross-country flight of at least 150 nautical miles total distance stopping at three separate locations. One leg of the flight must be at least 50 nautical miles between takeoff and landing locations	5 hours solo flight training including one cross-country flight of at least 100 nautical miles stopping at three separate locations. One leg of the flight must be at least 50 nautical miles between takeoff and landing locations
Solo Takeoffs and Landings	3 takeoffs and landings performed at airport with operating control tower	3 takeoffs and landings at an airport with an operating control tower

3.1.4 Instrument Rating

Under FAR 61, a pilot who applies for an instrument rating must hold at least a private pilot certificate. An instrument rating allows the pilot to fly under limited visibility, Instrument Flight Rules (IFR) conditions.

Table 2: Instrument Training Requirements Overview

Training	FAR 61	FAR 141
Ground school	Ground school or home study	35 hours for initial course and 15 hours for subsequent courses
Total Flight time	90 hours	30 hours for initial course and 20 hours for each additional course

Training	FAR 61	FAR 141
Takeoffs and Landings	Instrument approach at each airport during cross country flight. 3 kinds of approaches using navigation systems.	Instrument approach at each airport during cross country flight. 3 kinds of approaches using navigation systems.
Cross Country	50 hours cross-country flight time as pilot-in-command for a distance of at least 250 nautical miles along airways or ATC-directed routing for airplane. 100 nautical miles for helicopter.	Cross-country flight time as pilot-in-command for a distance of at least 250 nautical miles along airways or ATC-directed routing for airplane. 100 nautical miles for helicopter.
Instrument Training	15 hours	
Simulation time	Maximum of 30 hours	Maximum of 50% of total flight training

3.1.5 Commercial Pilot

FAR 61, a commercial pilot must have a Second Class Medical Certificate, private pilot certificate, instrument rating (or be enrolled in instrument rating course) and must have completed the training and flight time described in Table 3.

Table 3: Commercial Pilot Training Requirements Overview

Training	FAR 61	FAR 141
Total Flight Time	<u>250 hours for airplane</u>: 100 hours in powered aircraft with 50 hours in airplanes and 100 hours of pilot-in-command flight time with at least 50 cross-country hours <u>For helicopter rating: </u>pilot must have logged at least 150 hours of flight time with: - 100 hours in powered aircraft of which 50 must be in helicopters - 100 hours of pilot-in-command flight time including 35 hours in helicopters and 10 hours in cross-country flight in helicopters	
Training Time	20 hours of training	35 hours ground school 120 hours flight training for airplane or 115 hours for rotorcraft 55 hours dual instruction from CFI including 5 hours instrument training, 10 hours single-engine aircraft with retractable landing gear, cross-country flights of more than 100 nautical miles and 2 hour duration
Solo Flight	10 hours in either airplane or helicopter depending upon rating	10 hours in airplane or helicopter

3.1.6 Airline Transport Pilot

FAR 61, an airline transport pilot must have a First Class Medical Certificate, commercial pilot certificate, instrument rating or comparable military flight experience and must have completed the flight training in either Table 4 for airplane or Table 5 for helicopter.

Table 4: Airline Transport Pilot Training Requirements Overview for Airplane

Training	FAR 61 – Airplane	FAR 141 - Airplane
Total Flight Time	1500 hours of total time as a pilot that includes: - 500 hours of cross-country flight time - 100 hours of night flight time - 75 hours of instrument flight time - 250 hours of flight time in an airplane as pilot in command - Performed at least 20 takeoffs and landings	Meet aeronautical experience requirements in Subpart G of Part 61 of FAR 141 and complete 25 hours flight training with 15 hours instrument training

Table 5: Airline Transport Pilot Training Requirements Overview for Helicopter

Training	FAR 61 – Helicopter	FAR 141 – Helicopter
Total Flight Time	1200 hours that includes: - 500 hours of cross-country flight time - 100 hours of night flight time of which 15 must be in helicopters - 200 hours of flight time in helicopters - 75 hours of instrument flight time	Meet aeronautical experience requirements in Subpart G of Part 61 of FAR 141 and complete 25 hours flight training with 15 hours instrument training

3.1.7 Other Training

Additional training is required for operating complex or high-performance airplanes, pressurized aircraft capable of flying at high altitudes, tail-wheel airplanes or gliders.

Under FAR 61, no person may act as pilot in command unless they have performed at least three take offs and landings within the past 90 days. If the flight is at night, then at least three take offs and landings must have been performed at night in the past 90 days.

Under FAR 61, no person may act as pilot in command under IFR unless they have performed at least 6 instrument approaches, holding procedures and intercepting and tracking courses through the use of navigation systems.

3.1.8 Ratings

In addition to a pilot certificate, type ratings for different types of aircraft can be placed on the pilot certificate. For example, a pilot may have an instrument rating allowing him/her to fly under low visibility (IFR) weather conditions. Special authorizations can be issued in lieu of a type rating for up to 60 days if the Federal Aviation Administrator has:

- Authorized the flight or a series of flights
- Determined that equivalent level of safety can be achieved through the operating limitations on the authorization

Special authorizations can also be issued when the flight is in the United States and is a ferry flight, training flight, test flight or practical test for a pilot certificate or rating where the only compensation is for aircraft rental to complete the test.

3.1.9 Maneuvers

Under FAR 61, student pilots must demonstrate satisfactory aeronautical knowledge including:

- Applicable sections of Part 61 – Certification: Pilots and Flight Instructors and Part 91 – General Operating and Flight Rules
- Airspace rules and procedures for the airport where the solo flight will be performed
- Flight characteristics and operational limitations for the make and model of aircraft to be flown
- Performed the following maneuvers for an airplane:
    - Proper flight preparation procedures including preflight planning, power plant operation and aircraft systems
    - Taxiing or surface operations including runups (revving engine to ensure proper working)
    - Takeoffs and landings (normal and crosswind)
    - Straight and level flight
    - Turns in both directions
    - Climbs and climbing turns
    - Airport traffic patterns including entry and departure procedures
    - Collision avoidance, wind shear avoidance and wake turbulence avoidance
    - Descents, with and without turns, using high and low drag configurations
    - Flight at various airspeed from cruise to slow flight
    - Stall entries from various flight attitudes and power combinations with recovery initiated at the first indication of a stall and recovery from a full stall
    - Emergency procedures and equipment malfunctions
    - Ground reference maneuvers
    - Approaches to a landing area with simulated engine malfunctions
    - Slips to a landing
    - Go-arounds

Maneuvers for a helicopter include the maneuvers listed above and include the following:

- Hovering and hovering turns

- Rapid decelerations
- Simulated one-engine–inoperative approaches and landings for multi-engine helicopters

3.1.10 Cross-Country Flight Requirements

Under FAR 61, maneuvers required for solo cross country flight include:

- Use of aeronautical charts for VFR navigation using pilotage and dead reckoning with the aid of a magnetic compass
- Use of aircraft performance charts pertaining to cross-country flight
- Procurement and analysis of aeronautical weather reports and forecasts including recognition of critical weather situations and estimating visibility while in flight
- Emergency procedures
- Traffic pattern procedures that include area departure and arrival, entry into traffic patterns and approach
- Procedures and operating practices for collision avoidance, wake turbulence precautions and wind shear avoidance
- Recognition avoidance and operational restrictions of hazardous terrain features in the geographical area where the cross-county flight will be flown
- Procedures for operating the instruments and equipment installed in the aircraft to be flown
- Use of radios for VFR navigation and two-way communication
- Takeoff, approach and landing procedures including short-field, soft-field and crosswind takeoffs, approaches and landings
- Climbs at best angle and best rate
- Control and maneuvering solely by reference to flight instruments including straight and level flight, turns, descents, climbs use of radio aids and ATC directives

3.1.11 Pilot Logbooks

Training time and aeronautical experience must be logged in a manner acceptable to the Administrator. Logbook entries should contain the following:

- Date
- Total flight time or lesson time
- Location where the aircraft departed and arrived, or for lessons in simulator, location where lesson occurred
- Type and identification of aircraft, simulator as appropriate
- Name of the safety pilot
- Type of pilot experience
    - Solo
    - Pilot in command
    - Second in command
    - Flight and ground training received from authorized instructor
    - Training received in flight simulator from authorized instructor

- Conditions of flight
    - Day or night
    - Actual instrument
    - Simulated instrument conditions in flight or simulator

Logging of pilot time may be used to apply for certificate or rating and satisfy recent flight experience.

3.2 Aircraft Testing

FAR 91.203 through 91.221 describes the Equipment, Instrument and Certificate requirements, and FAR 91.401 through 91.421 explains aircraft maintenance requirements. The following sections provide an overview of aircraft testing requirements.

3.2.1 Mandatory Aircraft Maintenance & Inspections — Forever

All aircraft must undergo mandatory periodic maintenance and inspections every 50 hours, 100 hours, or annually depending upon how the aircraft is used.

3.2.2 Annual Inspections — Forever

Unlike an automobile that drives in and out of an inspection bay in as little as 5 minutes, an aircraft undergoes an annual inspection that can take days to complete.

The aircraft is taken into a hangar and literally taken apart, so that every component can be inspected and tested. Worn components are replaced, tweaks and adjustments to settings are made, improvements or updates are applied, lubricating fluids are analyzed by a laboratory then replaced with new ones, and complete records are entered into the aircraft's logbooks. Only when everything is perfect, is the aircraft recertified for return to flight by an FAA-designated inspector.

3.2.3 Mandatory Testing & Certification of Parts & Consumables — Forever

All materials and consumables used to make, repair, and operate aircraft are tested and certified by the FAA. Nothing, *and that means absolutely nothing*, can be used to make, repair, or operate an aircraft that is not specifically approved for use with that individual aircraft without the explicit written approval of the FAA.

3.3 Flight Plans[5]

Flight Plans can be filed for VFR, IFR and DVFR (Defense Visual Flight Rules) flights. Except for operations in or penetrating a Coastal or Domestic ADIZ (Air Defense Identification Zone) or DEWIZ (Distant Early Warning Identification Zone) a flight plan is not required for VFR flights. But filing a VFR flight plan is strongly recommended to ensure receipt of VFR Search and Rescue Protection.

Flights into ADIZ or DEWIZ require a flight plan for security purposes. IFR flights require a flight plan for safety purposes. A flight plan includes the following information:

- Type of flight plan (VFR, IFR or DVFR)
- Complete aircraft identification including "N" if applicable
- Designator for the aircraft
- True airspeed (TAS)
- Departure airport identifier code (i.e. SJC for San Jose International airport) or airport name
- Proposed departure time in Coordinated Universal Time (UTC)(Z)

- Appropriate VFR altitude to assist briefer in providing weather and wind information
- Route of flight using NAVAID identifier codes and airways
- Destination airport identifier code or airport name
- Estimated time en route in hours and minutes
- Any pertinent remarks
- Fuel on board in hours and minutes
- Alternate airport if desired
- Complete name, address and telephone number
- Total number of persons onboard (POB) including crew
- Predominant colors of aircraft for search and rescue
- Flight Service Station (FSS) for closing the flight plan
- Destination phone number to assist with search and rescue

3.4 Airspace Classifications[4]

All the open sky covering the United States – from less than an inch off of the ground to the edge of outer space — is part of America's airspace!

This airspace is divided into several standardized types, ranging from Class A through Class G – with A being the most restrictive and G the least restrictive. Each type of airspace has its own required level of Air Traffic Control services, and its own minimum requirements for pilot qualifications, aircraft equipment, and weather conditions. In addition to Classes A through G, other airspace is reserved for special purposes called Special Use Airspace (SUA).

Within the United States, airspace is either controlled or uncontrolled. Controlled airspace will have specific defined dimensions (e.g. altitude ranges or vertical boundaries, and an applicable surface area or horizontal boundaries). Within controlled airspace, Air Traffic Control (ATC) services are provided to all aircraft operating under Instrument Flight Rules (IFR), and to some aircraft operating under Visual Flight Rules (VFR).

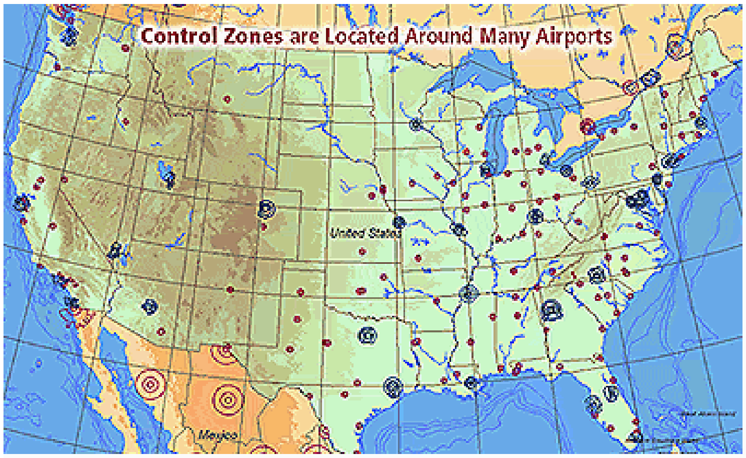


Figure 1: Control Zones

An airport with an operating control tower will almost always be surrounded by either Class B, C, or D airspace. Many people often refer to this airspace as a Control Zone. Though no longer an official FAA term, the interactive, color-coded, airspace map located at

http://www.gaservingamerica.org/how_work/work_airspace.htm##

shows all of the Control Zones surrounding America's Class B (shown in blue) and C (shown in magenta) airports.

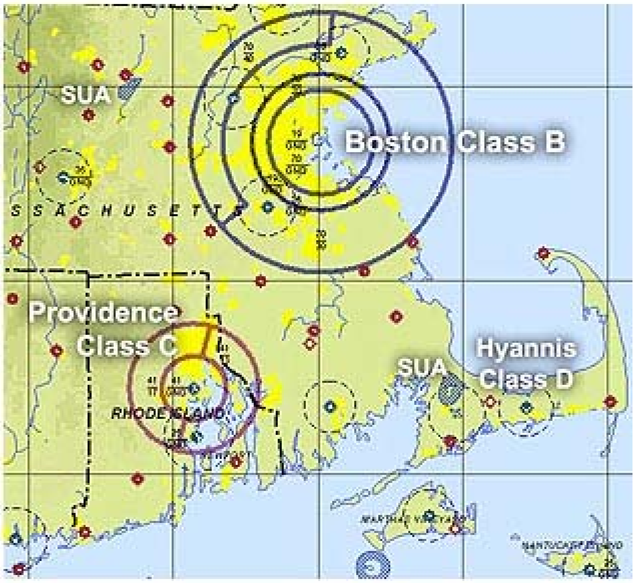


Figure 2: Sample Airspace Map

3.4.1 Class A Airspace

Class A airspace covers the entire U.S., and lies between 18,000 and 60,000 feet above mean sea level (MSL). All of the Jetways (Jet Routes) are in Class A airspace and it is primarily used by jets and airliners traveling over long distances between major cities. All flights in Class A airspace are conducted under Instrument Flight Rules (IFR); therefore pilots must hold an instrument rating and fly according to an active IFR flight plan. Pilots must obtain a clearance from ATC before entering Class A airspace, and maintain radio contact with ATC during flight. Aircraft must be equipped with an altitude-encoding transponder to provide aircraft location and altitude data to ATC radar equipment. A transponder is the radar beacon receiver/transmitter portion of the Air Traffic Control Radar Beacon System (ATCRBS) which automatically receives radio signals from the interrogations on the ground and selectively replies with a specific reply pulse or pulse group only to those interrogations being received on the mode to which it is set to respond.

3.4.2 Class B Airspace

Class B airspace surrounds the nation's busiest airports and airport hubs in cities like Boston, Chicago, Los Angeles, et al. Class B airspace is designed to help manage the traffic as aircraft takes off and lands at the airport. Therefore, it is shaped like a funnel to help aircraft in and out of the main airport.

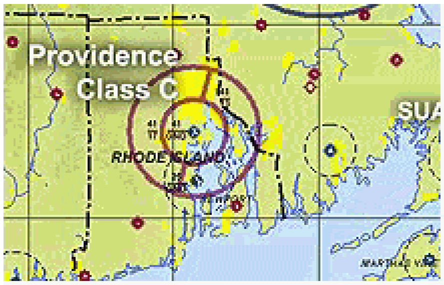
Boston Class B

Most Class B airspace extends from the surface to 10,000 feet MSL with a circular *diameter* of 40 nautical miles. Pilots must obtain a clearance from ATC before entering Class B airspace and maintain radio contact with ATC. Aircraft must be equipped with an altitude-encoding transponder.

Pilots must hold at least a private pilot certificate. If certain advanced training requirements are met, a Recreational or Student pilot certificate may be adequate although many Class B airports prohibit any student pilot solo flights. An instrument rating is not required; pilots may operate under Visual Flight Rules (VFR) in Class B airspace as long as they remain clear of clouds and have at least three miles of in-flight visibility.

3.4.3 Class C Airspace

Class C airspace surrounds busy airports not classified as Class B that have radar services for arriving and departing aircraft. Typical airports with Class C airspace would be Providence, Nashville, or Sacramento.

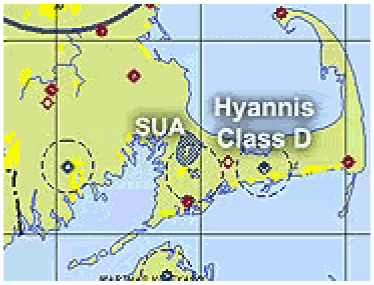


Most Class C airspace extends from the surface to 4,000 feet above ground level (AGL), with a circular diameter of 20 nautical miles.

An ATC clearance is not required in Class C airspace, but pilots must be in radio communication with ATC, and aircraft must be equipped with an altitude-encoding transponder. There are no additional pilot qualifications for operating in Class C, D, E, or G airspace

3.4.4 Class D Airspace

Class D airspace surrounds airports with operating control towers and weather reporting service that are not superseded by more restrictive Class B or C airspace.



Most Class D airspace extends from the surface to 2,500 feet above ground level (AGL), with a circular diameter of 4.3 nautical miles (5 statute miles).

Aircraft must establish and maintain two-way radio contact with the control tower before entering or operating in Class D. Weather minimums are the same as for Class C airspace.

3.4.5 Class E Airspace

Class E airspace includes all other controlled airspace in the U.S. The upper limit of Class E airspace is 18,000 MSL. However, the lower limit (where it starts) can be 14,500' MSL, or 10,000' MSL, or 1,200' AGL, or 700' AGL, or all the way to the surface of the earth.

Most non-airport or non-airway Class E airspace located east of the Rocky Mountains starts at 1,200' AGL, dropping lower over some airports. Most of the Class E west of the Rocky Mountains starts at 10,000' or 14,500' MSL. The Class E airspace above 10,000' MSL has greater visibility and cloud clearance minimums for VFR operations.

Class E airspace also surrounds airports that have weather reporting services in support of IFR operations, but no operating control tower. Weather minimums for these areas of Class E airspace are the same as for Class C and D airspace.

All airways that are not part of a higher grade of airspace are Class E airspace.

3.4.6 Class F Airspace

Class F airspace is not used in the United States.

3.4.7 Class G Airspace

Class G is uncontrolled airspace, so it includes all airspace in the U.S. that is not classified as Class A, B, C, D, or E. No ATC services are provided, and the only requirement for flight is certain visibility and cloud clearance minimums. Most of the airspace up to 1,200 feet AGL (Above Ground Level) is Class G airspace. There is virtually no Class G airspace above 1,200 feet AGL east of the Rocky Mountains.

3.4.8 Special Use Airspace (SUA)

Special use airspace (SUA) includes prohibited areas, restricted areas, warning areas, military operations areas (MOAs), alert areas, and controlled firing areas.

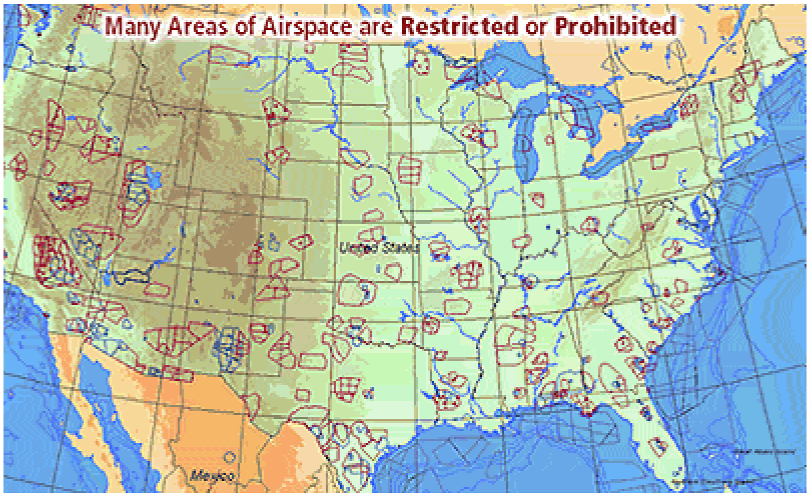


Figure 3: Special Use Airspace

In these areas, aeronautical activity must be limited, usually due to military use or national security concerns. You can see SUA on the interactive map located at: http://www.gaservingamerica.org/how_work/work_airspace.htm##

3.4.9 Other Airspace Areas

Other airspace areas include Airport Advisory Areas, Military Training Routes, and areas where Temporary Flight Restrictions (TFRs) or limitations/prohibitions apply. For example, TFRs are often established over large forest fires to help keep aircraft from straying into hazardous conditions.

3.5 Aircraft Operations[5]

Aircraft must be operated in accordance with FAR 91, General Operating and Flight Rules. The autonomous rotorcraft must be able to follow the right-of-way rules in FAR 91.113, Right-of-Way Rules: Except Water Operations and 91.115 Right-of-Way Rules: Water Operations. Generally, slower, less agile aircraft are given right of way by faster, easier to maneuver vehicles. For example, a hot-air balloon has the right-of-way over any other category of aircraft. When two aircraft are approaching head-on, each pilot must alter course to the right. Aircraft in final approach while landing has right-of-way over aircraft in flight or taxiing.

Other salient information from of FAR 91 is listed by section number below:

- FAR 91.117 states that no aircraft may fly more than 250 knots (288 mph) below 10,000 feet MSL (Mean Sea Level)
- FAR 91.119 says that except when taking off and landing, no aircraft may fly over congested areas below 1000 feet above the highest obstacle within 2000 feet of the aircraft
- FAR 91.121 contains tables with lowest usable flight level and adjustment factors for altimeter settings
- FAR 91.123 describes compliance with Air Traffic Control (ATC) instructions
- FAR 91.126 through FAR 91.135 discusses operating in each class of airspace beginning with Class G and ending with Class A
- FAR 91.137 and 91.138 discuss Temporary Flight Restrictions (TFRs) on the mainland and in Hawaii
- FAR 91.138 provides guidance regarding Emergency Air Traffic Rules
- FAR 91.141 states that no person may fly in the vicinity of an area to be visited by the President or Vice President or other public figures
- FAR 91.143 says that no person may fly in the proximity of space flight operations (shuttle take off and landing, etc.)
- FAR 91.151 through 91.159 describe the Visual Flight Rules
- FAR 91.167 through 91.193 describe the Instrument Flight Rules
- FAR 91.303 explains rules for aerobatic flight
- FAR 91.307 discusses parachutes and parachuting
- FAR 91.309 describes towing operations (e.g. towing of gliders)
- FAR 91.313 discusses operation of restricted civil aircraft
- FAR 133 describes Rotorcraft External-load operations

3.6 Aircraft Operations during Wildfires[6]

According to the Bureau of Land Management, aircraft play these important roles in fighting wildfires:

- Fire detection – includes aerial observation to find fires at the smallest size possible. For example, in the forests of East Texas, pilots fly small aircraft such as the Cessna 172 over the forest to detect wildfires or accidental fires started by campers, etc.

  Fire detection also includes determining the perimeter of a fire while it rages. A pilot with fire detection skills or a pilot and a fire expert fly over the fire and attempt to locate the edge. This is sometimes difficult because it is hard to see through smoke.

- Fire Assessment – also called Fire Intelligence. Aircraft is used to observe the fire and the ground forces fighting it. A visual of the fire provides decision makers important information necessary to develop strategies for extinction. Also, from time to time prescribed fires are set in the woods for resource benefits. These fires must be carefully managed and herded to accomplish the goal of the fire.

- Fire fighting – dropping water or retardant agents from helicopters or aircraft to put out the fire. For example, during the Malibu fires, helicopters scooped water from the ocean and drop it on the fire.

Pilots participating in fire fighting activities must have at least a private pilot's license. During a wildfire, the FAA issues temporary flight restrictions over the area and air traffic for fighting the fire is managed by assigning altitude ranges for each type of activity (from taxing ground forces to observation).

Flying during a fire is especially risky because pilots must fly low and slow over hot, generally mountainous terrain. Therefore, opportunities exist for unmanned fire fighting aerial vehicles to reduce this risk. Challenges for fire fighting UAV's are discussed in the next section.

3.7 Challenges for Flight Certification of UAV

Many facets must be considered when contemplating the challenges of flight certification of UAV's. First, there are several types of UAV's from pint-size helicopters to high-altitude, long-endurance (HALE) vehicles. They can be divided into the following classes[7]:

- Micro UAV's – drones weighing about 5 pounds and measuring 9 inches in diameter designed to fit inside a soldier's backpack and conduct surveillance over short distances. Examples include iStar, HeliSpy and Wasp.
- Mini UAV's – vehicles up to 6 feet long and weighing up to 90 pounds that were first used in the 1991 Gulf War for short-range reconnaissance to detect nearby threats in the field. Examples include Pointer, Dragon Eye and ScanEagle.

Tactical UAV's – larger than minis and perform similar tactical intelligence-gathering and target-acquisition missions with greater carrying capacity and endurance. Examples include Shadow 200, Pioneer, Dragon Warrior, GoldenEye, Hummingbird, Fire Scout, Eagle Eye and Dragonfly.

- HALE UAV's – High-altitude, long-endurance typically the size of business jets or 737s which survey large geographic areas and provide near real-time, high-resolution reconnaissance imagery. Examples include Ultra-LEAP, Predator B, Global Hawk and Proteus.

For purposes of this discussion, two types of UAV have been considered: the Mini UAV and HALE:

- Mini UAV - The Yamaha helicopters used for the Autonomous Rotorcraft Project (ARP) fit into the Mini UAV category. They were designed to accomplish reconnaissance and surveillance and can fly for about one hour with a 65 lb payload. The ARP rotorcrafts have already received special Airworthiness Releases to fly at Moffett Airfield and other authorized airfields for purposes of research, but so far flight has been under human control. The autonomous flight control system is scheduled for flight in the near term. Details of the airworthiness release are described below.
- HALE vehicles cruise at altitudes between 45,000 and 60,000 feet and can stay aloft for 24 hours at a time. They are controlled remotely by pilots on the ground thanks to satellite links that

convey images and commands in real time. HALE vehicles were used in the Afghanistan conflict and in the war against Iraq.

If these UAV's were to seek pilot certification, what type of pilot rating would be appropriate for the mini UAV and HALE? A definitive answer must take into account where and when the UAV would fly. Historically, new aircraft have flown in less populated areas until they establish a track record for safety. Therefore, the recreational pilot option might be sufficient since recreational pilots are limited in where they can fly. However, reconnaissance and surveillance seems to require the ability to cover more ground than 25 nautical miles from the UAV's home airport. HALE UAV's may be too large to take off at a small airport and may require a Class B or C airport.

The private pilot certification includes all the basic maneuvers necessary for safe, effective flight during VFR and an instrument rating would make it possible to fly with limited visibility. This may be a good option for the Mini UAV since they are a single engine aircraft similar to general aviation aircraft.

The multi-engine commercial pilot certificate requires a demonstration of the ability to handle multiple engines, which applies to HALE vehicles but not to ARP. The ATP certificate adds flight experience to ensure handling of various flight conditions in order to safely ferry passengers. While flight experience is always good, UAV's are not currently being considered as passenger vehicles.

Suppose the UAV takes the traditional route to pilot certification beginning with the private pilot licensure, what challenges would it encounter during flight training? First, minor challenges occur in obtaining a medical clearance and proper flight preparation including flight plans and preflight checks. These challenges are easily overcome by having a human meet the requirements and perform these tasks similar to the way HALE vehicles operate now.

Next, the UAV must perform flight maneuvers described in section 3.1.8. Since the rotorcraft is a helicopter, taxiing and surface operations can be handled by a human pilot who positions the rotorcraft for takeoff. Currently, the autonomous rotorcraft takes off and lands under human control, but research to-date indicates that autonomous take-off and landing are feasible. Additional types of sensors, like sonar altitude sensors, may be needed to augment the GPS system in order to find the ground for a soft landing. Autonomous takeoff and hovering at the proper altitude may also present challenges. HALE vehicles require runway clearance for takeoff, and assurance that other aircraft will not traverse their ascent to high altitude. According to the Air Force, there have been occasions when the FAA has cleared a flight path of civilian aircraft for an autonomous UAV, but that is not the norm.[8] This suggests a growing need for a strategy to accommodate autonomous aircraft while still maintaining a high degree of safety surrounding flight.

During normal flight, the innovative, ARP flight control system (FCS) contains advanced control laws (CLAW) making it possible for autonomous flight including: straight and level flight, turns in both directions, climbing and climbing turns, hovering and hovering turns, descents with and without turns, flight at various airspeeds and recovery from stalls. The ARP FCS can also handle approaches to the landing area with simulated engine malfunction. HALE vehicles would need a similarly robust autonomous FCS to accomplish these maneuvers.

"Detect, See and Avoid" Challenges

Bigger challenges occur when considering operations requiring interface with other pilots or the control tower such as safe entry into the airport traffic pattern and/or collision avoidance. These are commonly called "detect, see and avoid" maneuvers. Possible solutions to these challenges include:

- Required use of Type S Transponders on all aircraft making it possible for aircraft to identify others' location. The UAV could read Type S Transponders emissions and steer clear.
- Text messaging services are generally used when flying over large bodies of water where the distance makes voice communications less reliable. The UAV computers could read and parse the text message into commands that autonomous systems can understand.

- Onboard radio for relay to ground teams making it possible for a human pilot to monitor UAV flight and remotely perform “detect, see and avoid” maneuvers. Depending upon the complexity of the operation, a human pilot may be able to monitor multiple UAV’s.

Because HALE UAV’s fly at altitudes above commercial aircraft, they mainly face challenges when re-entering controlled airspace generally during takeoff and landing or during an emergency malfunction.

Finally, the UAV must log flight activity in a flight log. This could be a combination of computer-generated messages about the flight and notes from the human pilot in charge of this flight.

Distance Challenges

Some of the distance requirements for standard pilot classifications present challenges. In order for the ground station to maintain radio contact for a 25-mile cross-country flight, the height of the ground antennas would have to be increased significantly. It is possible that increased height could get to the point that it would create a flight obstruction just to maintain communication.

Perhaps a new, interim category could be developed that is tuned to operation within ~10 mile range of an (arbitrary) fixed point. Once the autonomous aircraft has been proven reliable and has an established safety history then it could fly longer distances.

Fire Fighting Challenges

In addition to the challenges described above, fire fighting UAV’s must be equipped with lightweight cameras and infrared cameras that can provide clear pictures of the fire to ground control in a timely fashion. Cost is also a factor.

Aircraft Maintenance Challenges

In some cases, UAV’s have been considered expendable and have not been maintained with the same rigor as human-powered aircraft. In order to fly in controlled airspace, aircraft must be rigorously maintained in accordance with FAR 91 for the safety of inhabitants living under the flight path.

Airworthiness Release

In order to fly out of Moffett Field, an airworthiness release was required from the Army and a permit from NASA Ames Research Center. The airworthiness release from the Army[9] contains the following information:

- References to Airworthiness Authority documentation from NASA Ames Research Center, Yamaha RMAX helicopter operation manual, controls documentation, yearly inspection criteria, pre-flight checklists, etc.
- Purpose of flight
- Configuration of fight including the helicopter and remote control transmitter
- Specific operation restrictions including outlawed maneuvers and operation requirements
- Special inspections and instructions
- Aircraft logbook entries
- Term of airworthiness release

The NASA permit[10] includes the following:

- Section 1 Permit Information:
    - Results of flight readiness review before the flight
    - Responsible parties
    - Description and Purpose of Project

  - Permitted operations
  - Special requirements including special equipment required or any hazardous operations or chemicals involved
  - Aircraft support services such as fuel, oil, oxygen, etc required
  - List of vehicles, personnel and frequency transmitters employed
  - Proof of insurance
- Section 2: Rotorcraft Remote Control Aircraft Operation Conditions
  - Authorized weather conditions (for example: weather at 500 feet AGL and 1 mile visibility)
  - Weekly Flight Schedule
  - Restrictions including only authorized personnel, aircraft movement and parking
  - Identification of safety observer
  - Location of flight (example: north end of the West parallel)
  - Rotorcraft RC personnel are responsible for knowing and complying with all applicable elements of the Airfield Operating Manual and must observe driving rules and speed limits in same
  - Only authorized, qualified pilots may conduct flights. (RC pilot qualifications are to be determined)
  - Emergency reporting
  - Notice that rotorcraft shall operate as if it is a full-sized aircraft using Moffett Field Class D airspace. Standard pilot to ATC radio procedures will be used including specific radio clearances required from ATC Control Tower
  - Autonomous and semi-autonomous rotorcraft operations were specifically not approved but instructions were provided for seeking approval of same
- Attachment 1
  - Picture and description of Yamaha RMAX helicopter
  - Description of Autonomous Rotorcraft Project
  - Flight Readiness Review presentation

NASA has also published a comprehensive flight research operating procedures manual titled: *AFDD Memorandum 95-1 Flight Research Standard Operating Procedures* to spell out aviation management, operations and safety, training and standardization, flight procedures, maintenance and aircraft modification guidelines.

4 CERTIFICATION OF FLIGHT SOFTWARE PER RTCA DO-178B

The previous section discussed the flight capabilities of the UAV as a whole. This section focuses on certification of UAV flight software. How does the FAA know when flight software works properly and is safe to fly? In the United States, software must undergo a certification process described in the Requirements and Technical Concepts for Aviation (RTCA) DO-178B which is enforced by the Federal Aviation Administration (FAA). During the certification process, the FAA regulatory authorities will be looking for evidence that all potential hazards have been identified and that appropriate steps have been taken to mitigate them. The UK and Europe have similar certification processes. Again, it seems likely that if UAV flight software can meet or exceed current FAA certification requirements it could be certified for flight.

In order to meet regulatory guidelines, developers must build a safety case as a means of documenting the safety justification of a system. The safety case is a record of all safety activities associated with a system throughout its life. Items contained in a safety case include the following:

- Description of the system/software
- Evidence of competence of personnel involved in development of safety critical software and any safety activity
- Specification of safety requirements
- Results of hazard and risk analysis
- Details of risk reduction techniques employed
- Results of design analysis showing that the system design meets all required safety targets
- Verification and validation strategy
- Results of all verification and validation activities
- Records of safety reviews
- Records of any incidents which occur throughout the life of the system
- Records of all changes to the system and justification of its continued safety

4.1 RTCA DO-178B[1]

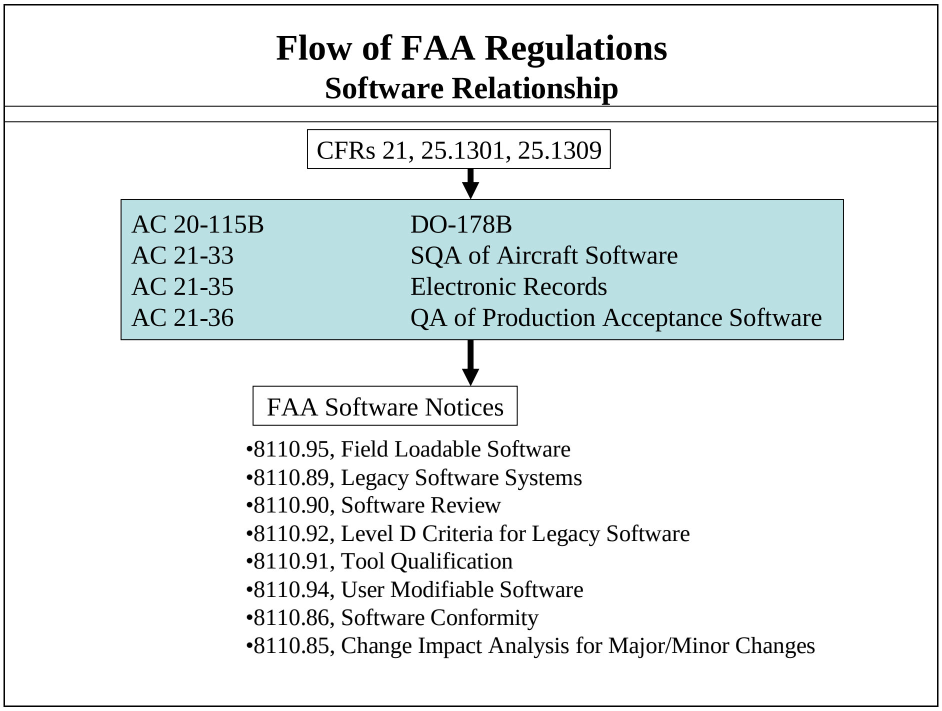
RTCA DO-178B, “Software Considerations in Airborne Systems and Equipment Certification” contains guidance for determining that software aspects of airborne systems and equipment comply with airworthiness certification requirements.

Written in 1980 by the Radio Technical Commission for Aeronautics (now RTCA, an association of aeronautical organizations of the United States from both government and industry), it was revised in 1985 and again in 1992. During the 1992 revision, it was compared with international standards: ISO 9000-3 (1991), “Guidelines for the Application of ISO 9001 to the Development, Supply and Maintenance of Software” and IEC 65A (Secretariat) 122 (Draft – 11-1991), “Software for Computers in the Application of Industrial Safety-Related Systems” and it is considered to generally satisfy the intent of those international standards.

RTCA also published the following documents to clarify DO-178B:

- DO-248B – explains best practices in applying DO-178B
- DO-278 – provides an extension to standards for ground-based facilities.

In addition to DO-178B, the FAA also considers the documents shown in the following diagram:



Flow of FAA Regulations
Software Relationship

CFRs 21, 25.1301, 25.1309

AC 20-115B	DO-178B
AC 21-33	SQA of Aircraft Software
AC 21-35	Electronic Records
AC 21-36	QA of Production Acceptance Software

FAA Software Notices

•8110.95, Field Loadable Software
•8110.89, Legacy Software Systems
•8110.90, Software Review
•8110.92, Level D Criteria for Legacy Software
•8110.91, Tool Qualification
•8110.94, User Modifiable Software
•8110.86, Software Conformity
•8110.85, Change Impact Analysis for Major/Minor Changes

Figure 4: Flow of FAA Regulations

The following flow shows the FAA approval process.

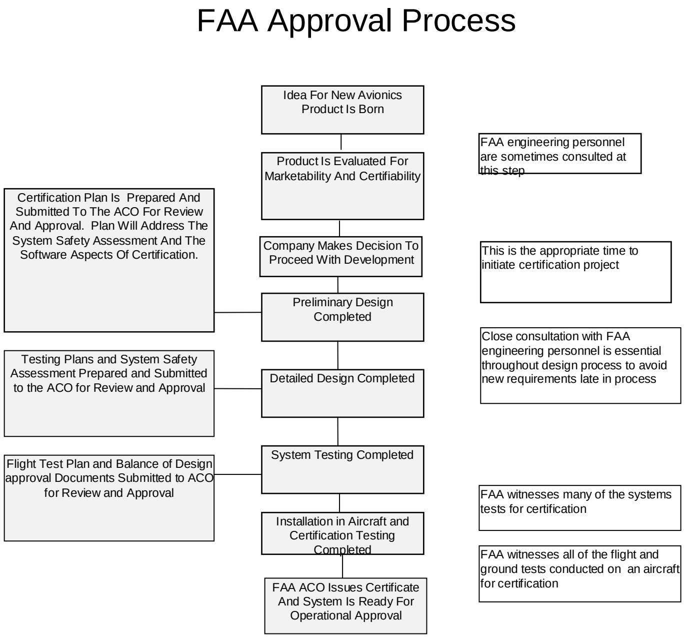

FAA Approval Process
Idea For New Avionics Product Is Born
FAA engineering personnel are sometimes consulted at this step
Product Is Evaluated For Marketability And Certifiability
Certification Plan Is Prepared And Submitted To The ACO For Review And Approval. Plan Will Address The System Safety Assessment And The Software Aspects Of Certification.
Company Makes Decision To Proceed With Development
This is the appropriate time to initiate certification project
Preliminary Design Completed
Close consultation with FAA engineering personnel is essential throughout design process to avoid new requirements late in process
Testing Plans and System Safety Assessment Prepared and Submitted to the ACO for Review and Approval
Detailed Design Completed
Flight Test Plan and Balance of Design approval Documents Submitted to ACO for Review and Approval
System Testing Completed
FAA witnesses many of the systems tests for certification
Installation in Aircraft and Certification Testing Completed
FAA witnesses all of the flight and ground tests conducted on an aircraft for certification
FAA ACO Issues Certificate And System Is Ready For Operational Approval

Figure 5: FAA Approval Process

4.2 DO-178B Software Level Definitions

Software can be divided into two broad categories based on the risk associated with software failure or defective software design:

1. **Mission critical** meaning a loss of capability leading to possible reduction in mission effectiveness[2]
2. **Safety critical** meaning a failure or defective design could cause a risk to human life[2]

DO-178B classifies software in more detail according to five levels described below; however, the overall idea is the same – more rigorous certification processes and methods are required for safety-critical software.

- Level A – software whose anomalous behavior would cause or contribute to a catastrophic failure that would prevent safe flight and landing
- Level B - software whose anomalous behavior would cause or contribute to a hazardous/severe-major failure condition. Hazardous/Severe-Major is defined as failure conditions that reduce the capability of the aircraft or crew to cope with adverse operating conditions to the extent that safety is jeopardized, the physical demands on the crew are excessive to the point of being impossible and serious or fatal injuries may occur.
- Level C - software whose anomalous behavior would cause or contribute to a major failure with significant reduction in safety, increase in crew workload or conditions impairing crew efficiency or discomfort or injury to occupants
- Level D - software whose anomalous behavior would cause or contribute to a minor failure that would not significantly reduce aircraft safety and where crew actions would not be impaired but the crew might be inconvenienced
- Level E - software whose anomalous behavior would have no effect on operational capability of the aircraft and would not increase crew workload[1]

4.3 DO-178B Safety-Critical Certification Requirements

DO-178B contains specific guidance for certification of safety-critical software to assure the safety of everyone involved in flight. In order to comply, suppliers in the aerospace industry must understand that DO-178B does not certify software as a unique, stand-alone product. Software is considered a part of the airborne system or equipment installed on the aircraft or engine.

4.3.1 Safety-Critical Certification Process

The certification process includes the following steps where the applicant is a supplier of aerospace software and the certification authority is the organization or person responsible within the state or country concerned with the certification:

- Applicant meets with the certification authority to establish the certification basis or criteria for the aircraft or engine
- Applicant develops a Plan for Software Aspects of Certification (PSAC) to meet the certification basis. The PSAC includes:
  - System overview explaining the:
    - System functions and their allocation to the hardware and software
    - Architecture
    - Processor(s)
    - Hardware and software interfaces
    - Safety features

- Software overview describing the software functions with emphasis on the proposed safety and partition concepts like resource sharing, redundancy, multiple-version dissimilar software, fault tolerance and timing/scheduling strategies
- Certification considerations including:
    - Means of compliance
    - Software level (A-E)
    - Summary of the justification provided by the system safety assessment process including potential software contributions to failure conditions
- Software Life Cycle section containing a description of the software with reference to respective detailed software plans and a summary explaining how the objectives of each software life cycle process will be satisfied and which organization is responsible. The minimum software life cycle data that may be submitted to the Certification Authority is the:
    - PSAC
    - Software Configuration Index (SCI) – described in Appendix C
    - Software Accomplishment Summary (SAS) – described in Appendix D
    - Software Verification Cases and Procedures

However, according to Boeing Wichita Development and Modification Center (WDMC), a FAA-Designated Alteration Station, the minimum is rarely enough. A successful presentation to the FAA should include the following artifacts. The items highlighted in bold type are specific to DO-178B. Other documents are standard life cycle material; however, the FAA requires that these artifacts be updated regularly so they contain the most recent information rather than having modifications appended at the end of the document.

1. **Plan for Software Aspects of Certification (PSAC)**
2. Software Development Plan (SDP)
3. Software Verification Plan (SVP)
4. Software Configuration Management Plan (SCMP)
5. Software Quality Assurance Plan (SQAP)
6. Software Requirements Standards (SRS)
7. Software Design Standards (SDS)
8. Software Code Standards
9. Software Requirements Data
10. Design Description (SDD)
11. Source Code
12. Executable Object Code
13. Software Verification Cases and Procedures
14. Software Verification Results
15. Software Life Cycle Environment Configuration Index
16. **Software Configuration Index (SCI)**
17. Problem Reports
18. Software Configuration Management Records
19. Software Quality Assurance Records
20. **Software Accomplishment Summary (SAS)**

In order to obtain certification by the FAA, the applicant must prove that objectives have been met. For Level A there are 66 objectives, for Level B there are 65 objectives and for Level C there are 62 objectives.

  - Software Life Cycle Data section including a description of any data to be produced and controlled by the software along with how the data relate to each other. It should also include information about how the data will be submitted to the certification authority (diskette, CD…) and the form of the data (i.e. text file, binary file…).
  - Schedule
  - Additional considerations like tool qualification, previously developed software, COTS software, et al.
- Certification authority assesses the PSAC for completeness and consistency by comparing it to the certification basis
- Certification authority satisfies itself that proposed software level is appropriate
- Certification authority apprises applicant of any issues that must be satisfied prior to certification
- Certification authority determines whether the aircraft or engine (including software) complies with the certification basis by reviewing the SAS and evidence of compliance. The Certification authority may also review at its discretion the software life cycle processes and their outputs.[11]

4.3.2 Additional Certification Considerations

Additional certification considerations include:

- Use of Previously Developed Software
- Tool Qualification
- Alternative Methods

4.3.2.1 Use of Previously Developed Software

Frequently, software will rely upon COTS or other previously developed software. Certification of these modifications takes into account the following:

- Change of software level
- Impact of modification on requirements, architecture, installation, development environment, target processor or other hardware and integration with other software

DO-178B lists specific methods for ensuring the safety of any modifications. These methods include:

- Reverse engineering to obtain software life cycle data that is inadequate or missing
- Comparison of failure conditions to previous application
- Upgrading development baseline if product history is necessary to satisfy certification objectives
- Repetition of hardware/software compatibility reviews
- Additional integration tests and reviews as necessary

4.3.2.2 Tool Qualification

Qualification of a tool is needed when processes described in DO-178B are automated. The objective is to ensure that the tool provides at least the same confidence as the manual process. The concept of tool qualification is unique to civilian aviation. Other industries do not typically require tool qualification prior to use.

For qualification purposes, tools are divided into two categories:

- Development Tools – tools whose output is part of airborne software and can introduce errors
- Verification Tools – tools that cannot introduce errors, but may fail to catch them

4.3.2.2.1 Qualification of Development Tools

Software development tools must be qualified to ensure they do not introduce errors into airborne software. Qualification criteria include the following:

- The software development process for the tool must satisfy the same objectives as the development process for airborne software
- The software level must be the same for the development tool and the airborne software. A different level may be applied if the tool provides a significant reduction in verification activities (like an auto-coder).
- The tool must be verified against Tool Operational Requirements. This may involve a trial period during which tool output is verified.

The certification authority qualifies a software development tool after considering the following:

- The tool must meet specific criteria outlined in the Tool Qualification Plan which contains:
    - Configuration identification of the tool
    - Details of the certification credit sought
    - Software level
    - Tool qualification activities to be performed
    - Tool qualification data to be produced
- The Tool Accomplishment Summary (similar to the Software Accomplishment Summary described in a Section 6.4) must be provided illustrating compliance with the Tool Qualification Plan.

4.3.2.2.2 Qualification of Verification Tools

Verification tools must be qualified to make sure that the tools catch the errors they were designed to find. Qualification criterion includes checking that the tool complies with its Tool Operational Requirements under normal operational conditions.

The certification authority qualifies a verification tool after inspecting the SAS and other materials necessary to prove that the tool complies with the PSAC.

4.3.2.3 Alternative Methods

Alternative methods may be used to support software qualification. DO-178B describes the following alternative methods:

- **Formal methods** involving the use of formal logic, discrete mathematics and computer-readable language to improve the specification and verification of software
- **Exhaustive Input Testing** for situations where the inputs and outputs of software can be bounded and exhaustively tested
- **Software reliability models** including methods for estimating the post-verification probabilities of software errors. At the time of publication, DO-178B did not consider these techniques mature enough for safety critical software.
- **Product service history** demonstrating that the software has a track record of safety

An alternative method cannot be considered in isolation from the software development processes. The applicant must show that the alternative method satisfies the objectives of DO-178B.

In order to use an alternative method, the applicant must specify the following in the PSAC:

- Impact of the proposed method on the software development process and life cycle data
- Rationale behind the alternative method clearly showing how it meets safety objectives

4.3.3 Modified Condition and Decision Coverage (MCDC)

Modified Condition/Decision Coverage is a structural coverage criterion required by DO-178B for Level A software. It addresses exercising of Boolean expressions throughout the software, presumably because Boolean logic is commonplace in flight-critical software, especially in control laws. Each decision (a top-level Boolean expression) must be exercised to check both True and False outcomes.

MCDC levies further coverage requirements if a decision is composed of multiple conditions (a condition is a Boolean subexpression of a decision) connected by Boolean operators, as in (A and (B or C)). The additional requirement is to demonstrate that each condition can independently influence the outcome of the decision. That is, there exists a set of value for all other conditions in the decision for which toggling the value of this one condition will toggle the outcome of the decision. For example, in the decision (A and (B or C)), a value of False for B and True for C will demonstrate that A can independently affect the outcome of the decision, as the following truth table illustrates:

A	B	C	(A and (B or C))
T	F	T	T
F	F	T	F

where T = True and F = False

Here, changing A from T to F while holding the values of B and C constant changes the value of the decision. There may be other combinations of values for B and C which will also demonstrate the independence of A, but one combination is all that is needed. Likewise, conditions B and C must be demonstrated to independently affect the outcome of the decision. It can be shown that a minimum of (N + 1) test cases will be needed to accomplish MCDC for a decision containing N distinct conditions.

There is one other, somewhat unrelated, requirement included in MCDC: each entry and exit point of a subprogram must be exercised. This requirement was most likely included for completeness to ensure explicit coverage of these entry and exit points for Level A systems.

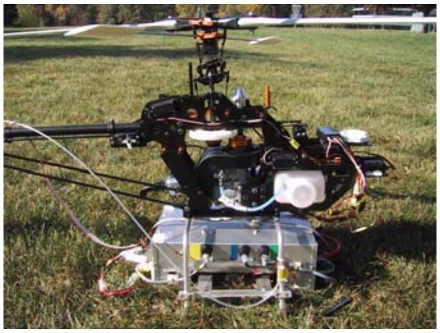
Beyond the simple cases where decisions consist of familiar Boolean operators and all distinct conditions, there is controversy surrounding the meaning of MCDC and how to apply it. Investigation is under way at NASA Langley to study the variations that exist and to recommend ways of promoting a uniform interpretation of MCDC.[12]

5 CURRENT RESEARCH TOWARD FAA CERTIFICATION

Current trends and research toward FAA certification of autonomous flight vehicles include, but are not limited to, work underway at NASA and DARPA:

- **Access 5 Project** at NASA Ames Research Center - Dallas Denery (POC). Access 5 stands for "access to controlled airspace in 2005". The project team is looking into the technology, simulation, flight demonstration and policies and procedures issues surrounding autonomous flight for HALE UAV's with special emphasis on "detect, see and avoid" technologies.

- **DARPA SEC (Software Enabled Control) Program** - Multi-project initiative to study autonomous flight. OGI School of Science & Engineering, Oregon Health & Science University was working towards autonomous helicopter flight similar to ARP. Contact: John Bay, Program Manage; Principal Investigator: Richard Kieburtz. The following was taken from a slide dated November 2002. Plans include autonomous take off and landing by March 2003.



Instrumented X-Cell 60 helicopter delivered by MIT
- Clone of MIT's tested configuration
- Instrumentation
  - IMU
  - GPS
  - Compass
  - Altimeter
  - Flight computer -- 300 MHz Pentium running QNX 4
  - Telemetry transmitter packaged with batteries in a dynamic vibration isolation unit – approx. 8lb. payload

Simulators
- Non-real-time simulator on Windows
  - Nonlinear flight dynamics model
- Real-time HIL simulator on QNX
  - drives servos, models sensors

- **Other Documentation**
  "Guidance for Unmanned Aerial Vehicles (UAV) Operations, Design Specification, Maintenance and Training of Human Resources", NATO Committee for European Airspace Coordination (CEAC), Document AC/92-D/967 (ORIGINAL: ENGLISH dated 25 November, 1996).

  "Equipment, Systems and Installations in Part 23 Airplanes", Federal Aviation Administration Advisory Circular AC 23.1309-1C, December, 1999.

6 APPENDIX A: ACRONYMS

Term	Definition
ARC	Ames Research Center
FAA	Federal Aviation Administration
EIA	Electronic Industries Association
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Organization for Standardization
MIL STD	Military Standard
NASA	National Aeronautical Space Administration
NPD	NASA Policy Directive
NPG	NASA Procedures and Guidelines
RTCA	Requirements and Technical Concepts for Aviation
V&V	Verification & Validation

Note: *More Acronyms: http://www.ksc.nasa.gov/facts/acronyms.html*

7 APPENDIX B: GLOSSARY

AGL: Above ground level

Certification: process for demonstrating that system safety is satisfactory for flight operation

IFR: Instrument Flight Rules means weather conditions below the minimum for flight under visual flight rules. Marine layer fog is an example of an IFR weather condition.

Mission critical: loss of capability leading to possible reduction in mission effectiveness but cannot cause a risk to human life

Modified Condition And Decision Coverage (MCDC): defined as checking that *"every point of entry and exit in the program has been invoked at least once, every condition is a decision that the program has taken all possible outcomes at least once, every decision has been shown to independently affect that decision's outcome. A condition is shown to independently affect a decision's outcome by varying just that condition while holding fixed all other possible conditions."*[1]

PSAC: Plan for Software Aspects of Certification

Safety-critical: failure or design error could cause a risk to human life

VRF: Visual flight rules means weather conditions do not interfere with visibility. A bright sunny day with no clouds is an example VFR weather condition.

Validation: process of determining that the requirements are correct and complete

Verification: evaluation of results of a process to ensure correctness and consistency with respect to the input and standards provided to that process

8 APPENDIX C: SOFTWARE ACCOMPLISHMENT SUMMARY (SAS)[1]

The SAS is the primary document for showing compliance with the Plan for Software Aspects of Certification (PSAC). It contains the following:

- System overview explaining the:
    - System functions and their allocation to the hardware and software
    - Architecture
    - Processor(s)
    - Hardware and software interfaces
    - Safety features

  Also describes any differences from the system overview in the PSAC.
- Software overview including software functions with emphasis on the proposed safety and partition concepts like resource sharing, redundancy, multiple-version dissimilar software, fault tolerance and timing and scheduling strategies. Also describes any differences from the system overview in the PSAC.
- Certification considerations including a restatement of PSAC certificate considerations and description of any differences.
- Software characteristics including the executable object code size, timing and memory margins, resource limitations and the means of measuring each characteristic
- Software Life Cycle section containing a description of the software with reference to respective detailed software plans and a summary explaining how the objectives of each software life cycle process will be satisfied, which organization is responsible and the certification liaison responsibilities. Also describes any differences from the system overview in the PSAC.
- Software Life Cycle Data section including a description of any data to be produced and controlled by the software along with how the data relate to each other. It should also include information about how the data will be submitted to the certification authority (diskette, CD…) and the form of the data (i.e. text file, binary file…). Also describes any differences from the system overview in the PSAC.
- Additional considerations section that summarizes certification issues that may warrant the attention of the certification authority
- Change history
- Software status section including a summary of problem reports unresolved at the time of certification
- Compliance statement section stating compliance with this document and summarizing the methods used to demonstrate compliance and any additional rulings or deviations for plans, standards or this document.

9 APPENDIX D: SOFTWARE CONFIGURATION INDEX (SCI) [1]

The SCI identifies the configuration of the software and should identify the following:

- Software product
- Executable object code
- Source code components
- Previously developed software
- Software life cycle data
- Archive and release media
- Instructions for building the executable object code
- Reference to the Software Life Cycle Environment Configuration Index – identifies the environment where the software will run
- Data integrity checks, if used

10 REFERENCES

[1] *Software Considerations in Airborne Systems and Equipment Certification,* Document No RTCA (Requirements and Technical Concepts for Aviation) /DO-178B, December 1, 1992. (Copies of this document may be obtained from RTCA, Inc., 1140 Connecticut Avenue, Northwest, Suite 1020, Washington, DC 20036-4001 USA. Phone: (202) 833-9339)

[2] Interview with Dale Mackall, Sr. Dryden Flight Research Center Verification and Validation engineer on January 16, 2003

[3] *FAR/AIM 2000*, Jeppesen Sanderson Training Products, Jeppesen Sanderson Inc. p. F-47.

[4] Federal Aviation Administration (FAA) website: http://www2.faa.gov/ and FAR 73

[5] *FAR/AIM 2000*, Jeppesen Sanderson Training Products, Jeppesen Sanderson Inc.

[6] Interview with David Dash, Bureau of Land Management (BLM) on June 25, 2003.

[7] Lopez, Ramon. "The Revolution Will Not Be Piloted," *Popular Science,* June 2003.

[8] Interview with Vince Crum, AFRL/VACC June 17, 2003

[9] Memorandum dated April 16, 2001 by Department of the Army Aeroflightdynamics Directorate US Army Aviation and Missile Command Ames Research Center

[10] NASA RMAX RC Permit dated April 18, 2001

[11] RTCA DO-178B – Overview of Aircraft and Engine Certification p. 45

[12] Email dated 2/21/03 from Dr. Vdot Santhanam, Boeing Wichita Development and Modification Center (WDMC)